TI INVENTION / INNOVATION DISCLOSURE

TI- 360036
original
(revised)

TI IV
1377

SEND COMPLETED FORM TO: TI CORPORATE PATENTS

ATTN:	Tina Smith
E-Mail:	tina-smith@ti.com
FAX:	(972) 917-4418
Mail Station	M/S 3999
PC Drop	PPC-E3

HELPLINE: Warren Franz

E-Mail	w-franz@ti.com
PHONE:	(972) 917-5271
FAX:	(972) 917-4418

If you are employed by a TI subsidiary company, send this form to your site coordinator.

To prepare your invention disclosure, follow the step-by-step directions on the form that follows. Type or print answers to the questions in the spaces provided.

PLEASE PROVIDE ANSWERS TO ALL OF THE QUESTIONS OTHERWISE THERE COULD BE DELAYS IN PROCESSING

If you already have an engineering spec, please send it with your invention disclosure. Computer documentation and drawings, marketing foils, notebook entries, paper manuscripts, articles, and any other material that you already have can be copied or sent electronically.

RECEIVED
MAR 26 2003
PATENT DEPT

30895

[1]PATENT DISCLOSURE FORM

DOCKET NO. TI-**(to be filled in by Patent Activity)**

IF ELECTRONICALLY TRANSMITTED, PROCESSING OF YOUR DISCLOSURE CANNOT BE COMPLETED WITHOUT A FOLLOW-UP COPY SIGNED AND DATED BY ALL INVENTORS AND AT LEAST ONE WITNESS.

1. Please suggest a descriptive title for your invention:

   Frequency-domain subchannel transmit antenna selection and power pouring for multi-antenna transmission.

2. **This invention supports strategy: (check 1 or more)**

☒ **BCG - WLAN application**

☐ DLP
☐ Materials
☐ Fab/Processes
☐ Assembly/Test/Packaging
☐ Other

DSPS
☐ Wireless
☐ Video
☐ Set Top
☐ Application Specific
☒ Remote/Access/Networking
☐ Emerging Markets
☐ Mixed Signal & Logic
☐ Mass Storage
☐ Broadband Access

3. **What is the problem solved by your invention?**

The performance of wireless local area network (WLAN) systems is determined by the data rates achieved between the access point (AP) WLAN transceiver and the set of station (STA) WLAN transceivers communicating with it. There are a wide range of possible operating conditions between the AP and STAs. Typically, the achievable rates decrease as distance between transceivers increases. The network efficiency is determined by the number of STAs in the network, the performance between the AP and each STA (which depends on the STAs location in the network), and the data rates achieved by each STA.

RECEIVED
MAR 26 2003
PATENT DEPT

David Magee 3/25/03   HSE 03-25-2003

Many single-radio-chain WLAN cards exist (legacy equipment) mostly adhering to the IEEE 802.11b, 802.11a, and 802.11g standards. Newer multi-radio WLAN solutions will be entering the market shortly. [refer to the 802.11 standards]

In this disclosure we describe an invention that employs multiple radio chains in a WLAN transceiver to extend the range and network efficiency of a WLAN network. The technique applied in the multi-radio WLAN transceiver is backward compatible with the existing standards and achieves performance gains when communicating with all legacy WLAN equipment as well as the newly emerging equipment.

4. What is your solution to the problem?

In the following, we describe a WLAN device capable of simultaneously transmitting multiple different signals and simultaneously receiving multiple different signals all in the same bandwidth. This WLAN device features multiple transmitter and receiver antennas, radios, and modulator/demodulator chains. The multiple element WLAN device is generically referred to as a multi-antenna WLAN device.

Background Information:
MIMO: A multi-antenna WLAN transmitter produces a set of signals that each pass through separate signal paths for digital modulation, analog and radio frequency processing, and wireless transmission over the antennas. There are several examples of prior art systems designed for multiple-input antennas and multiple output antennas (MIMO) where the transmitter splits and encodes the transmit signals in a manner that the receiver can exploit a diverse channel and knowledge of the encoding and achieve the highest possible rate, reach, and throughput. The MIMO algorithm employed in these designs typically attempts to achieve a linear increase in data rate as the number of transmit and receive antennas increase linearly. For example, with 2 transmit and 2 receive antennas, one can theoretically double the data rate. The encoding technique of splitting a transmit signal in time, and distributing the signal across the transmit antennas in space has become known as space-time coding. When combined with a multicarrier modulation scheme such as OFDM, this is often referred to as space-time-frequency coding. A multi-antenna MIMO receiver is responsible for processing the received signal to effectively determine the data transmitted from each transmit antenna.

Power Pouring: In the 3GPP third generation wireless standard, multiple antennas may be used. A technique named TXAA is used to adaptively weight signals for transmission from each antenna. The generally accepted technique for maximizing SNR in wireless communication with another device under maximum power constraints is to select the transmit antenna that results in largest power at the receiver. For the two-antenna

Mayer 3/25/03

HSE 03-25-2003

example, one should pour all power onto the transmit antenna resulting in the largest received power at the receiver. In this case, assume the time-domain channel response for transmission over antenna one is h_1 and for antenna two is h_2. Note that for any non-binary weighting of h_1 and h_2 the received power is less than the zero/one weighting:

$$\text{Max}\ (|h_1|^2, |h_2|^2) >= (a^*|h_1|^2 + (1-a)^*|h_2|^2) \text{ for any a, } 0<=a<=1.$$

In 3GPP systems, this power pouring is done across the entire signal bandwidth, resulting in the transmit signal coming exclusively from one of the two antennas (the one resulting in higher received power at the receiver).

Legacy Issue:
An enormous number of legacy single-antenna WLAN transceivers exist. While a multi-antenna WLAN transceiver can vastly improve performance when operating against another multi-antenna WLAN device, a technique is needed for gain improvements for a multi-antenna AP communicating with legacy single-antenna STAs.

Current Invention:
We now disclose a simple technique for enabling a multi-antenna WLAN device to achieve performance improvements when communicating with a single-antenna WLAN device or when communicating with a multi-antenna WLAN device operating in a legacy single-antenna mode. The multi-antenna WLAN receiver analyzes data received from another WLAN transmitter and determines channel statistics for each receive antenna (e.g. received power level in each subchannel for each antenna, interference level, etc.) Based on the channel statistics, the multi-antenna WLAN transmitter then determines a set of weighting vectors for each transmit antenna chain. A single-antenna transmit signal is replicated and input into each transmit chain where it is multiplied by the weighting vector for that signal chain. The weighting vectors can be computed based on various criteria. By design, the composite signal emitted from the set of transmit antennas appears to a single-antenna receiver as though a single-antenna transmitter had sent it. In this manner, it is fully interoperable with the full range of single-antenna transceivers and demodulation techniques. The benefit of the invention is that performance of a single-antenna receiver is increased because the transmitter can best use the subchannels available to each antenna chain to improve performance at the receiver. For example, if the multi-antenna transceiver detects very low power in subchannel k of antenna 1, and high power in subchannel k of antenna 2, then the transmitter will transmit on subchannel k of antenna 2, and the single-antenna receiver will have good SNR in subchannel K. Hence, the transmitter technique has effectively filled in a spectral null that the receiver would have experienced in subchannel k if the transmission had only been sent over antenna 1.

An example of the subchannel power pouring technique applied to a 2-antenna transceiver communicating with a 1-antenna transceiver using 4 frequency subchannels is shown in Figure 1. The 2-antenna transceiver analyzes the power of the channel response based on a signal transmitted from the single-antenna transceiver. The 2-antenna transceiver then determines onto which antenna the transmitted power should be poured for each subchannel. The signal X[k] for transmission is poured either entirely onto antenna 1 ($X_1[k] = X[k]$ and $X_2[k]=0$) if $|H1[k]| > |H2[k]|$ or entirely onto antenna 2

RECEIVED
MAR 2 6 2003
PATENT DEPT

Dand Meyer 3/25/03 HSE 03-25-2003

($X_1[k] = 0$ and $X_2[k] = X[k]$) if $|H1[k]| < |H2[k]|$. In the example shown with the example channel responses shown, the power observed in the channel responses causes power to be poured as follows: $X1[k] = \{X[0]\ \ 0\ \ X[2]\ \ 0\}$ and $X2[k] = \{0\ \ X[1]\ \ 0\ \ X[3]\}$.

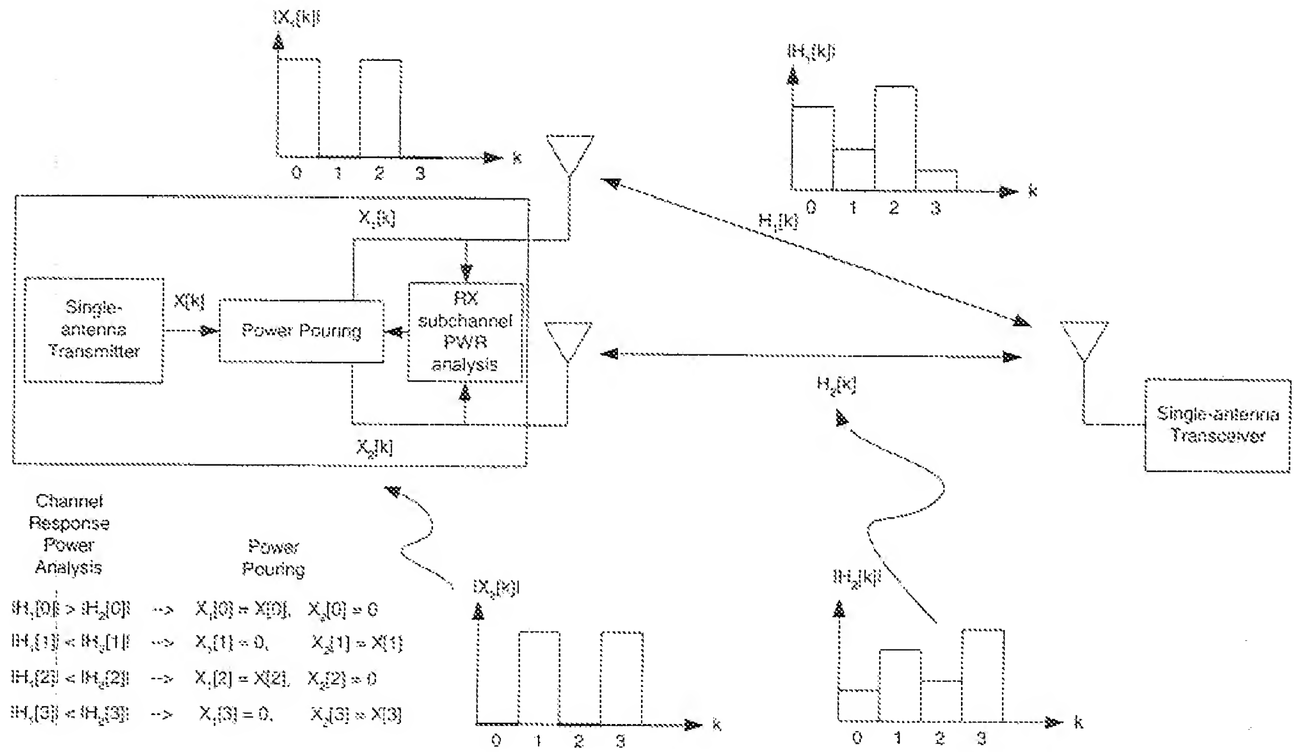

Figure 1: Example of the subchannel power pouring technique applied to a 2-antenna Transceiver communicating with a 1-antenna transceiver using 4 subchannels.

A variety of other algorithms can be used to determine the per-chain weighting vectors. Our preferred choice of a binary weighting vector is computationally very tractable and achieves very good performance. Along the lines of the binary antenna power pouring used in 3GPP, this technique also chooses the antenna on which to place all the transmit power. However, the current invention facilitates transmit antenna selection on a subchannel-by-subchannel basis and offers gain for frequency selective channels even when the total channel powers are similar.

The concept can be extended to applying power pouring across subchannels in order to normalize power across the band to achieve a certain receiver performance, e.g. frame error rate (FER). By applying this multi-antenna power control, the minimum energy required for a given reception threshold.

The performance increase is obtained by appropriate splitting on a subchannel basis in the 802.11a/g OFDM system, or on a frequency-band by frequency-band in single-carrier 802.11b system.

David Magee 3/25/03 H. S. E. 03-25-2003

One implementation of the invention in context of a 2-antenna 802.11a/g transceiver is shown in Figure 2. A particular single-antenna 802.11a/g transceiver transmits an OFDM signal and the multi-antenna transceiver captures and analyzes to determine the appropriate weighting vectors S and S' for use in transmission back to that single-antenna transceiver. The multi-antenna transceiver forms a composite transmit signal by taking the frequency-domain IFFT input from a single-antenna transmitter and duplicating this frequency-domain signal for use as input to the two different transmit chains. The weighting vectors S and S' are applied to each of the frequency-domain signals in each of the antenna chains, and an IFFT is performed on each weighted transmit vector, producing two separate transmit time-domain signals which are sent over the two antennas.

One implementation of the invention in context of a 2-antenna 802.11b transceiver is shown in Figure 3. A particular single-antenna 802.11b transceiver transmits a signal and the multi-antenna transceiver captures and analyzes to determine the appropriate weighting vectors S and S' for use in transmission back to that single-antenna transceiver. The multi-antenna transceiver forms a composite transmit signal by taking the output of a single-antenna transmitter, duplicating the signal and using as input to the two different transmit chains, transforming the signal into its frequency-domain components (e.g. with the FFT), applying the weighting vectors S and S' to the signals in the two chains, transforming back to time-domain (e.g. with IFFT), applying overlap-add (OLA) techniques to smooth the time-domain effective filter response, and finally transmitting the two separate signals over the two transmit antennas.

Performance gains of the multi-antenna power pouring technique for the OFDM version of frequency-domain subchannel power pouring (binary selection vectors) are shown in Figures 3 and 4 for 802.11a/g modulation and QPSK rates 1/2 and 3/4 coding rates respectively. Gains over single-antenna performance are 2.5 dB and 3.5 dB respectively at frame-error rates of about 10^-2.

Hand Mazur 3/25/03 H.S.E. 03-25-2003

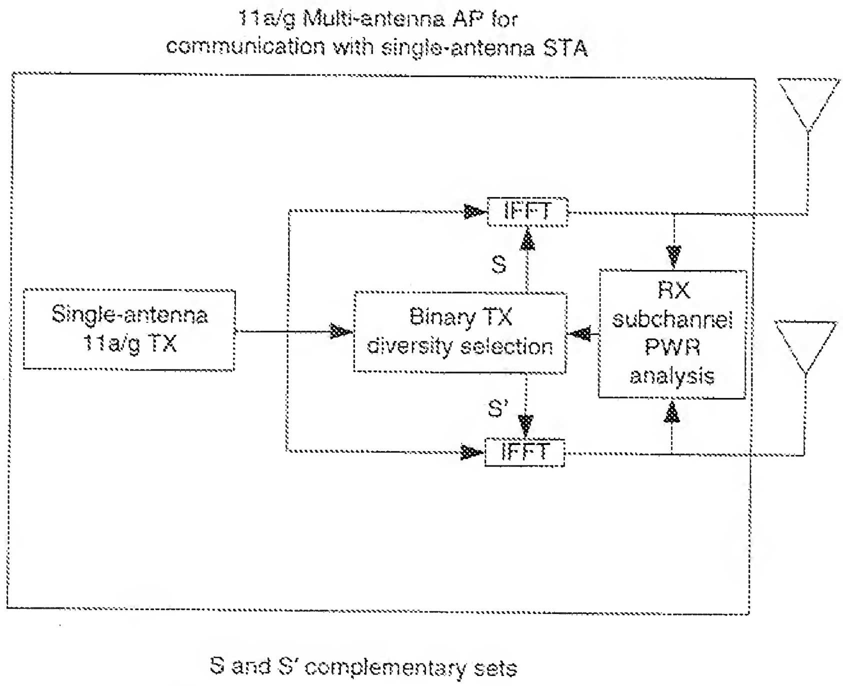

Figure 2 IEEE 802.11 a/g OFDM Mode

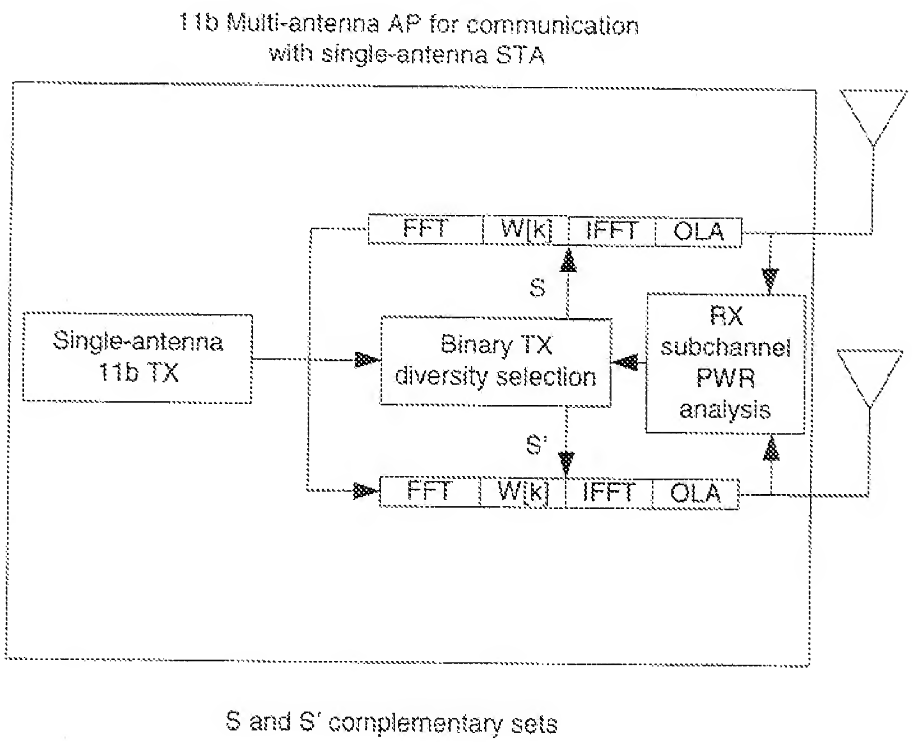

Figure 3 IEEE 802.11b/g Single-carrier Mode

3/25/03 H.S.E 03-25-2003

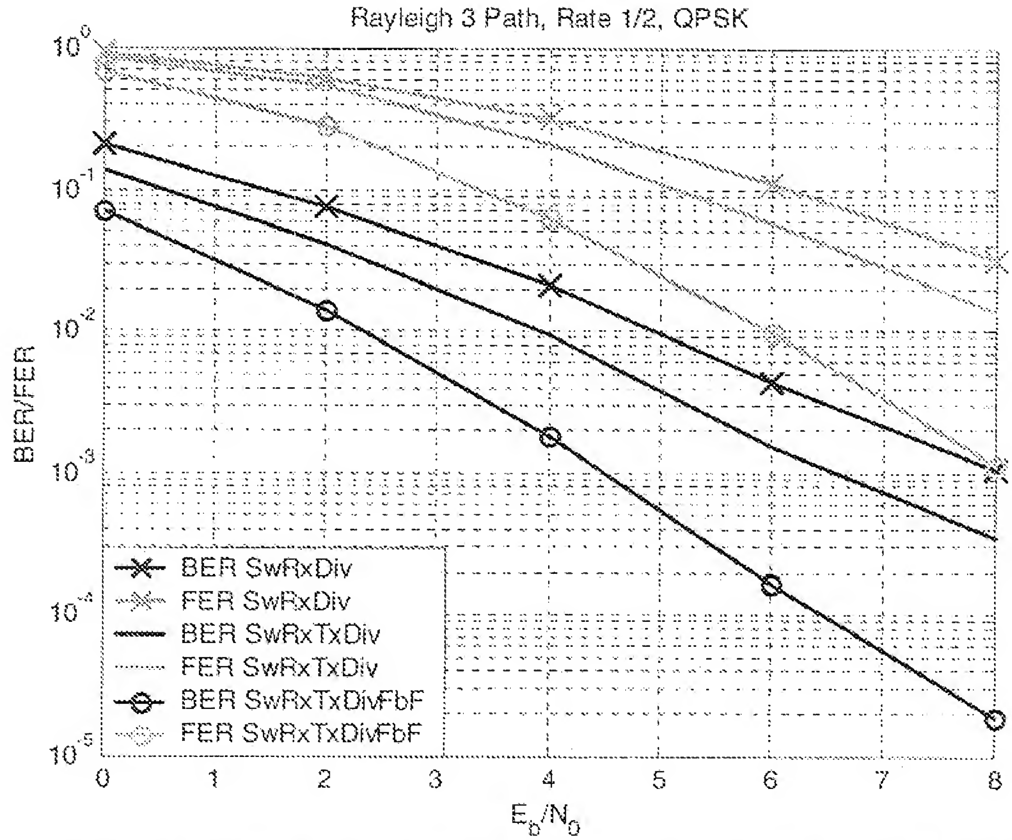

Figure 4 Example performance improvement with a 2-antenna WLAN transmitter communicating with a single-antenna 802.11a/g WLAN receiver in rate 1/2 QPSK mode. Both bit-error rate (BER) in blue and frame-error rate (FER) in green are shown on these plots. Lines with x's show performance for single-antenna transmitter, single-antenna receiver. Solid lines show performance when the best of two transmit antennas is chosen for transmission (as in 3GPP power pouring). Lines with o's show performance of the frequency-by-frequency power pouring across the two antennas based on a binary selection vector for each antenna chain. At a BER of 10^-2 the performance gain is about 2.5 dB over the single-antenna link.

David Meyer 3/25/03 H.S.S 03-25-2003

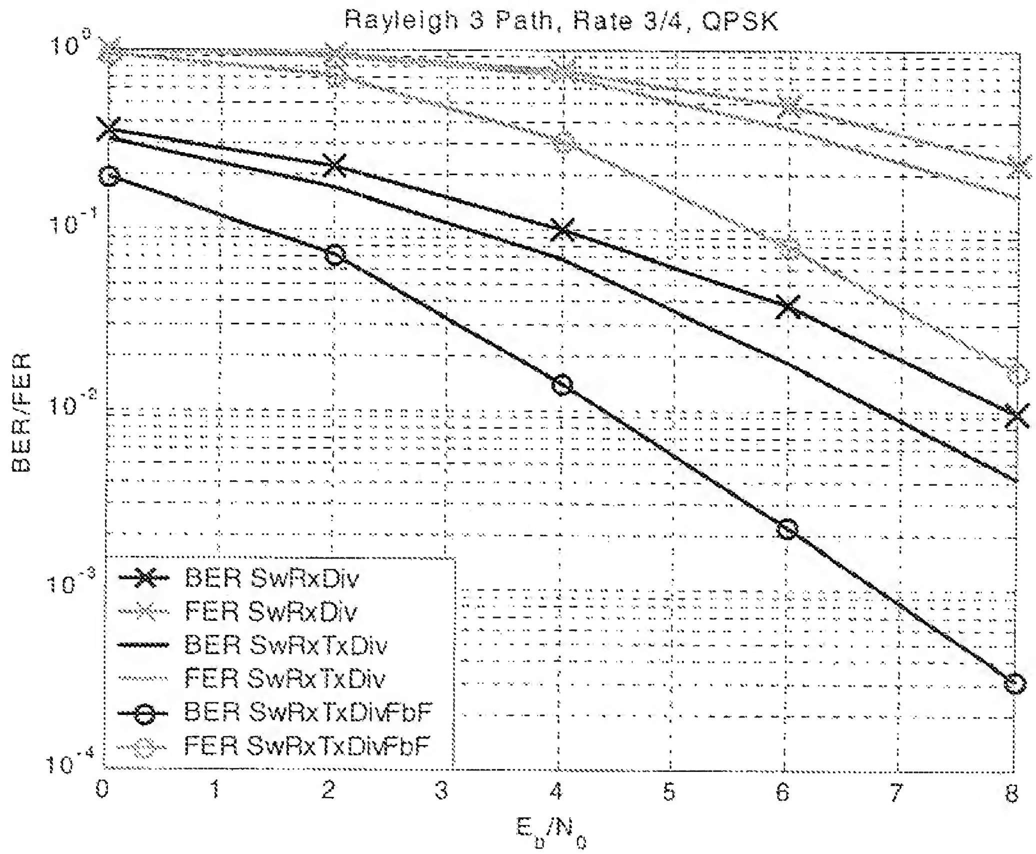

Figure 5 Example performance improvement with a 2-antenna WLAN transmitter communicating with a single-antenna 802.11a/g WLAN receiver in rate 3/4 QPSK mode. Both bit-error rate (BER) in blue and frame-error rate (FER) in green are shown on these plots. Lines with x's show performance for single-antenna transmitter, single-antenna receiver. Solid lines show performance when the best of two transmit antennas is chosen for transmission (as in 3GPP power pouring). Lines with o's show performance of the frequency-by-frequency power pouring across the two antennas based on a binary selection vector for each antenna chain. At a BER of 10^-2 the performance gain is about 3.5 dB over the single antenna link.

5. **When was your solution first conceptually or mentally complete?**

   Date: January 20, 2003

6. **What is the first tangible evidence of such completion?**

   Date: Email to Anand, Eko, Don, Sri, Muhammad on 1/20/03.

RECEIVED
MAR 26 2003
PATENT DEPT

David Magee 3/25/03

H. A. E 03-25-2003

7. **What is different about your solution, compared with other solutions to the same problem?**

Best performance, very simple, and backward compatible.

8. **What are the advantages of your solution?**

Performance improvements for a multi-antenna WLAN device when operating against legacy single-antenna WLAN devices. Does not require modification to the IEEE 802.11 WLAN standards.

9. **What TI products, processes, projects or operations currently implement your invention?**

Prototype implementation that is planned for intersection with future version of TNET1130+

10. **What is the date of the first implementation?**

Date: 2/10/03 in simulation, 3/1/ 03 on prototype

11. **What record exists to prove this date?**

RECEIVED
MAR 26 2003
PATENT DEPT

Dates of simulation codes by Srinath Hosur.

12. **Is there any future implementation planned?**

Yes ☒ **No** ☐

If so, please furnish the TI PART No. or project name

Yes, the invention is currently being implemented in an advanced prototype system and will likely be part of the next generation wireless LAN chipset, which will be successor to the TNETW1130+.

13. **Has the invention been published or disclosed to anyone outside of TI?**

Yes ☐ **No** ☒

When?

If planned - when? (Catalog, advertising, data book, application note, conference paper, magazine article, TI TJ, proposal document.)

Was there a nondisclosure agreement (NDA)? Not Applicable

David Magee 3/25/03 H.S.E. 03-25-2003

Yes ☐ No ☐

14. **Has a TI product incorporating the invention been publicly introduced, quoted, sampled or shipped?**

Yes ☐ No ☒

When? We've announced to our customers that the chipset is under development. We have not mentioned the innovative material disclosed herein. If planned--when? Customers will begin working with initial versions 3Q2001.

15. **Was the invention conceived or first implemented in the performance of a government contract or subcontract?**

Yes ☐ No ☒

Contract #: Not Applicable.

THE INVENTION DESCRIBED BY THIS DISCLOSURE IS SUBMITTED PURSUANT TO MY EMPLOYMENT AGREEMENT WITH TEXAS INSTRUMENTS INCORPORATED OR A TI SUBSIDIARY (SPECIFY):

Has this disclosure been previously sent to the Patent Department electronically (unsigned)?

Yes ☐ No ☒

RECEIVED
MAR 26 2003
PATENT DEPT

[signature] 3/25/03 H.S.C. 03-25-2003

PLEASE PRINT ALL INVENTOR INFORMATION.

Inventor 1's Name:	Michael Oliver Polley
Home Address:	7617 Windmill Lane Garland, TX 75044
E-Mail Address:	polley@ti.com
Employee #:	A0204819
TI Division & Cost Center	003 - 05113
Phone #:	214-480-4371
Pager #:	972-879-4193
Country of Citizenship:	USA
Inventor 1's Signature:	Michael Oliver Polley
Date:	2/18/03

Mail Station: 8649

RECEIVED
MAR 26 2003
PATENT DEPT

Inventor 2's Name: Srinath Hosur

Home Address: 8800 Canyonlands Drive
Plano, TX 75025

E-Mail Address: hosur@ti.com

Employee #: A0199599

TI Division & Cost Center 003 - 05113

Phone #: 972 480-4432

Pager #: No pager

Country of Citizenship: India

Inventor 2's Signature: H. Srinath

Date: 15th Feb 2003

Mail Station 8649

RECEIVED
MAR 2 6 2003
PATENT DEPT

Inventor 3's Name:	Muhammad Zubair Ikram
Home Address:	430 E. BUCKINGHAM RD. #410 RICHARDSON, TX 75081
E-Mail Address:	mzi@ti.com
Employee #:	864755
TI Division & Cost Center	003 - 05113
Phone #:	480-3132
Pager #:	No pager
Country of Citizenship:	~~USA~~ PAKISTAN
Inventor 3's Signature:	Zubair Ikram
Date:	2-18-03

Mail Station: 8649

RECEIVED
MAR 26 2003
PATENT DEPT

Inventor 4's Name: Donald P. Shaver

Home Address: 7938 Fallmeadow Lane
Dallas, TX 75248

E-Mail Address: shaver@ti.com

Employee #: 130594

TI Division & Cost Center 003 - 05113

Phone #: 214-480-4349

Pager #: No pager

Country of Citizenship: USA

Inventor 4's Signature: Donald P Shaver

Date: February 17, 2003

Mail Station: 8649

Inventor 5's Name: Eko Onggosanusi

Home Address: 1430 McClure Drive, Allen, TX 75013

E-Mail Address: eko@ti.com

Employee #: 216230

TI Division & Cost Center 003 - 05113

Phone #: 214-480-x809

Pager #: No pager

Country of Citizenship: USA

Inventor 4's Signature:

Date: 02/17/2003

Mail Station: 8649

Inventor 6's Name: Anand Dabak

Home Address: 8625 Kendall Drive, plano, TX 75025

E-Mail Address: dabak@ti.com

Employee #: A0196012

TI Division & Cost Center 003 - 05113

Phone #: 214-480-x4-389

Pager #: No pager

Country of Citizenship: x USA

Inventor 4's Signature: [signature]

Date: 17th February 2003

Mail Station: 8649

RECEIVED
MAR 26 2003
PATENT DEPT

◆ ◆

This invention disclosure with any attachments was read and understood by me on
March 25, 2003 (date read and understood).

Witness 1: [signature] Date signed 3/25/03

This invention disclosure with any attachments was read and understood by me on
March 25, 2003 (date read and understood.

Witness 2: Henry S. Eits Date signed 03-25-2003

RECEIVED
MAR 26 2003
PATENT DEPT